# Cassava Leaves as Human Food[1]

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*The use of cassava leaves as human food is reviewed and their value as a source of protein and vitamins for supplementing predominantly starchy diets reemphasized. The problem of the toxicity of the leaves is considered, and the effects on both nutritive value and toxicity of the traditional methods of preparing the leaves, such as drying, pounding, and long periods of boiling, are described and discussed. Loss of nutrients, particularly vitamins, occurs during processing but remaining levels can still make an important contribution to the diet. HCN levels are reduced considerably by the processing methods, although the toxic effects of residual levels need further investigation.*

The cassava plant (*Manihot esculenta* Crantz) is cultivated over most of the nonarid tropical world, mainly for its roots, which have been estimated to provide the staple food for over 500 million people in the developing countries (Lancaster et al., 1982). In some areas where cassava is grown, the leaves are also consumed, usually as a vegetable or as a constituent in a sauce, as an accompaniment to the main staple, which may or may not be cassava. Unlike the roots that are essentially carbohydrate, the leaves are a good source of protein and vitamins which can provide a valuable supplement to the predominantly starchy diets that are only too prevalent among the economically disadvantaged elements in the tropical world.

A number of authors have stressed the nutritive value of leafy vegetables in the diet of peoples inhabiting tropical regions and the need to encourage their use (Norman, 1972; Oomen, 1964; Terra, 1964). The last-named author deals in some detail with the significance of cassava leaves, in particular as a source of protein and vitamins; this aspect has been reemphasised more recently by Obioha (1972), who recommended that industrial means of blending cassava leaves into acceptable edible forms should be sought and backed up by educational programmes.

While in some countries, such as Tanzania (Wyllie and Huxley, 1976), efforts are being made to increase the production of plant protein from cassava, there are still many areas of the tropical world where the nutritive value of cassava leaves is less appreciated and hence its potential value not exploited. Indeed, in some countries cassava leaves are regarded as a poor man's food and only eaten when other preferred leaves are unavailable (Masseyeff and Cambon, 1955; Whitby, 1972), and in many countries not used at all.

The aim of the present paper is to review the literature on the traditional uses and the nutritional value of cassava leaves as a human food and to reemphasise their potential for human food in the developing world, where nutrient deficiencies are a widespread problem.

## CASSAVA LEAF

Cassava is a perennial shrub varying greatly in height and degree of branching, ranging from cultivars with tall unbranched stems reaching 5 m in height to cul-

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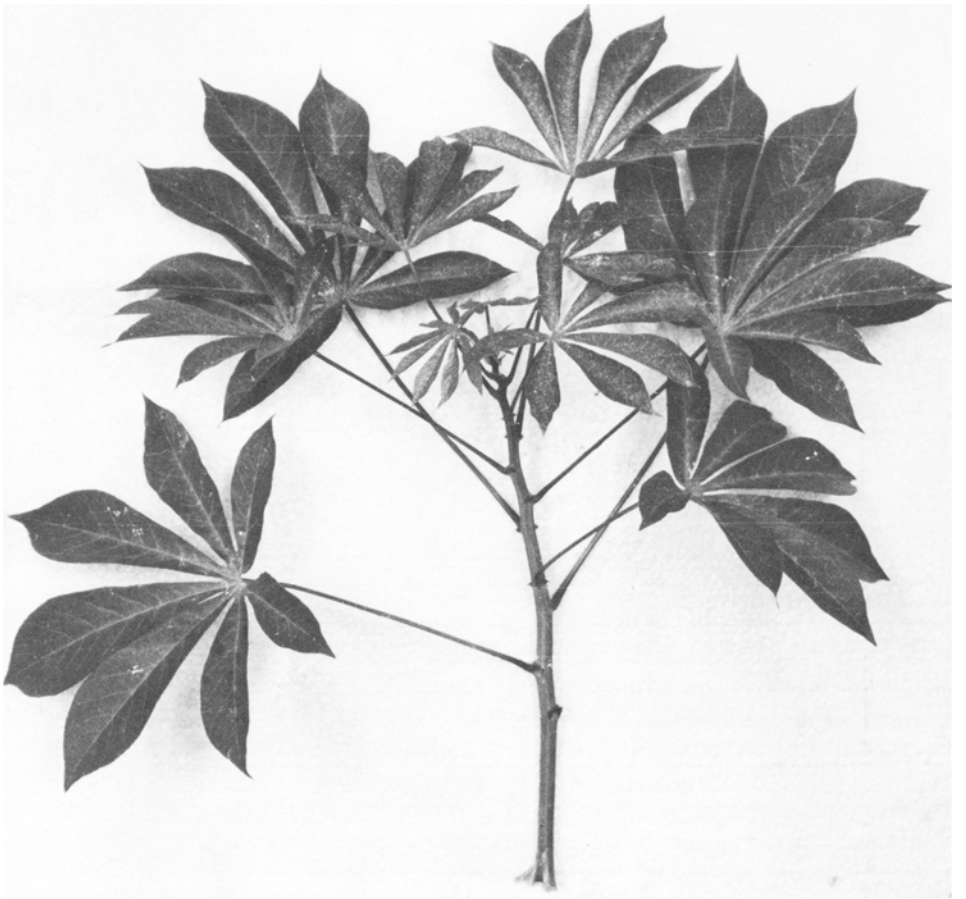

**Fig. 1.** Typical cassava leaves (copyright D. G. Coursey).

tivars branching profusely from about 1 m or less above ground level. The stems are woody and slender with the leaves borne towards the apex and with prominent leaf scars lower down. The petiolate, palmate leaves are arranged spirally and are variable in size, colour, and number and shape of lobes, although generally the fully-developed leaves are 5–7 lobed and the lobes are usually within the range 4–20 cm in length by 1–6 cm in width (Purseglove, 1968). Typical leaves are shown in Fig. 1.

The obtainable yield of cassava leaves varies considerably, depending upon such factors as rainfall, density of planting and cultivar. Age of the cassava plant also affects total leaf yield. Studies in Colombia of total dry matter yield per ha in 2 cultivars showed a higher yield in plants of 11-mo-growth compared to 9-mo-old plants (1.17 and 1.86 t dry matter per ha after 11 mo compared to 0.89 and 0.64 t dry matter per ha respectively after 9 mo), with no further increase after 12 mo growth (G. Gomez, 1982, priv. comm.). The yield also depends on the frequency of leaf harvests and this in turn also affects the root yield. In 2 recent

TABLE 1. EFFECTS OF FREQUENCY OF LEAF HARVESTS ON YIELDS OF CASSAVA LEAF AND ROOT.

| Harvesting frequency of leaf | Fresh leaf yield t/ha | | | | Fresh root yield after 12 mo t/ha | | | |
|---|---|---|---|---|---|---|---|---|
| | Kangu[a] | 02864[a] | Isunkakiyan[b] | TMS 30211[b] | Kangu[a] | 02864[a] | Isunkakiyan[b] | TMS 30211[b] |
| Frequently[c] | 5.7 | 6.9 | — | — | 4.9 | 15.4 | — | — |
| Once a mo | 22.7 | 24.5 | 7.7 | 13.6 | 11.0 | 25.2 | 3.5 | 16.6 |
| Every 2 mo | 16.3 | 17.6 | 4.1 | 11.9 | 14.0 | 35.8 | 5.5 | 24.6 |
| Every 3 mo | — | — | 4.5 | 7.6 | — | — | 12.2 | 25.2 |
| Control | 0 | 0 | 0 | 0 | 14.5 | 30.2 | 14.4 | 37.3 |

Source: [a] Lutaladio and Ezumah, 1981.
[b] Dahniya, 1981.
[c] Whenever leaves mature enough for use as a vegetable.

studies the greatest leaf yields were obtained by harvesting once a month after an initial period of 4–5 mo growth (Dahniya, 1981; Lutaladio and Ezumah, 1981). Yields are shown in Table 1 which also serves to illustrate the differences amongst cultivars.

However, cassava is most generally grown primarily as a root crop and it is thus important that leaf harvesting should not too greatly reduce root yields. While it has been shown in a number of studies that harvesting leaves can reduce root yield, and in general the more frequent the leaf harvest, the greater the reduction in root crop (Ahmad, 1973; Kumar and Mandal, 1975; Montaldo and Montilla, 1977), it has recently been demonstrated that an optimum leaf harvest frequency can be determined in order to obtain a good leaf yield without significantly reducing the root yield (Table 1). From this work harvesting leaves at 2–3-mo intervals has been recommended for the best all round yields (Dahniya, 1981; Dahniya et al., 1981; Lutaladio and Ezumah, 1981).

## NUTRITIVE VALUE

Typical values of the nutrient content of cassava leaves are shown in Table 2 which indicates that they are rich in protein, calcium, iron and vitamins, comparing favourably with other green leaves and other vegetable foods generally regarded as good protein sources.

A wide range of protein contents has been reported, varying considerably among cultivars. In a review of earlier literature, Terra (1964) reports a range of 4.0–9.6% on a fresh weight basis, while Rogers (1959), who tested over 100 samples, found a range of 20.6–36.4% crude protein (total N $\times$ 6.25) on a dry weight basis. The results of more recent analyses are shown in Table 3 with figures as high as 11.8% (fresh weight) and 39.9% (dry weight) (Tupynamba and Vieira, 1979).

The leaf protein yields per ha in 6 different cultivars, grown at a research station in Malaysia, were estimated to range from 242–953 kg after 9-mo growth which the authors compare with spinach yields of about 400 kg of protein per ha after 3–4 mo (Yeoh and Chew, 1976). In Nigeria protein yields from cassava leaves as high as 1,344 kg per ha have been reported although no indication is given of the age of the plants (Anonymous, 1969).

Attempts have been made to increase the protein content of the leaves of some

TABLE 2. COMPOSITION OF CASSAVA LEAVES AND SELECTED OTHER FOODS IN TERMS OF PER 100 G EDIBLE PORTION, FRESH WEIGHT.

| | Calories | Moisture % | Protein g | Fat g | Total carbo-hydrate g | Fibre g | Ash g | Ca mg |
|---|---|---|---|---|---|---|---|---|
| Cassava leaf—raw | 91 | 71.7 | 7.0 | 1.0 | 18.3 | 4.0 | 2.0 | 303 |
| | 60 | 81.0 | 6.9 | 1.3 | 9.2 | 2.1 | 1.6 | 144 |
| Chinese cabbage—raw | 17 | 94.2 | 1.7 | 0.2 | 3.1 | 0.7 | 0.8 | 102 |
| Spinach—raw | 19 | 93.0 | 2.4 | 0.4 | 2.8 | 0.7 | 1.4 | 62 |
| Soybean—whole seeds, salted, black | 330 | 20.1 | 18.1 | 9.4 | 46.3 | 8.5 | 6.1 | 29 |
| Wheat—whole grain, hard | 332 | 12.5 | 11.6 | 2.2 | 72.1 | 2.1 | 1.6 | 48 |
| Maize—yellow | 349 | 13.6 | 9.1 | 4.2 | 71.7 | 2.3 | 1.4 | 14 |
| Rice—unhulled, rough | 341 | 13.7 | 5.8 | 2.3 | 73.4 | 10.4 | 4.8 | 24 |

Source: [a] Food Composition Table for Use in Africa. Food and Agric. Org. and US Dept. Health, Educ. and Welfare, 1968.
[b] Food Composition Table for Use in East Asia. Food and Agric. Org. and US Dept. Health, Educ. and Welfare, 1972.

cassava cultivars by crossing with other *Manihot* species (Nobre et al., 1973). For example, by crossing a cassava cultivar Saracura 696 containing 28.40% protein by dry weight in the leaf with an unidentified species referred to as *Manihot* sp-2401 containing 21.30% protein, a hybrid was obtained whose leaves contained 34.20%. The protein content of the root was also increased significantly although there was an accompanying disadvantage in that the HCN content of the root was increased considerably.

While green leaves are high in crude protein content, other factors such as a high fibre content may keep consumption at a level lower than that needed to supply the required daily intake of protein, especially in children (Oke, 1973): hence the interest in leaf protein concentrates (LPC) as a means of supplementing the diet. Following an early study on the extraction of protein from various west African plant leaves including cassava (Byers, 1961), LPC has been obtained successfully from cassava leaves by a number of researchers (Akinrele, 1963; Fafunso and Oke, 1976; Nandakumaran et al., 1978; Oke, 1973; Tupynamba and Vieira, 1979). Fafunso and Oke (1976) extracted leaf protein from 15 cassava cultivars. The total nitrogen extracted averaged 58.7%, most of which was found to be true protein while the average protein nitrogen extracted was 44.9%.

The amino acid composition of cassava leaves has been determined in a number of studies and the results of some of these, together with the amino acid profile of cassava LPC are shown in Table 4. Other analyses have also been carried out (Adrian et al., 1969; Adrian and Peyrot, 1970; Arnal-Peyrot and Adrian, 1970; Busson and Bergeret, 1958; Oke, 1971, 1973; Otoul, 1973, 1974; Yeoh and Chew, 1976). There is variation in the results but they all show that with the exception of methionine the essential amino acid values in cassava leaves exceed those of the FAO reference protein. The variation in amino acid content of the leaves may be due, not only to cultivar, but also to ecological conditions and/or methods of analysis, as variation among cultivars grown under identical conditions was shown to be insignificant (Otoul, 1974). The portion of leaf taken as a sample and the age of the plant are also responsible for different findings (Otoul, 1973). Yeoh

TABLE 2. CONTINUED.

| | P mg | Fe mg | Vitamin A βcarotene equivalent μg | Thiamine mg | Ribo-flavin mg | Niacin mg | Ascorbic acid mg | Reference |
|---|---|---|---|---|---|---|---|---|
| Cassava leaf—raw | 119 | 7.6 | 11,775 | 0.25 | 0.60 | 2.4 | 8 | a |
| | 68 | 2.8 | 8,280 | 0.16 | 0.32 | 1.8 | 82 | b |
| Chinese cabbage—raw | 46 | 2.6 | 2,305 | 0.07 | 0.13 | 0.8 | 53 | b |
| Spinach—raw | 39 | 3.9 | 3,640 | 0.06 | 0.22 | 0.7 | 56 | b |
| Soybean—whole seeds, salted, black | 163 | 1.1 | 520 | 0.07 | 0.27 | 18.6 | — | b |
| Wheat—whole grain, hard | 382 | 3.3 | 0 | 0.37 | 0.12 | 4.6 | 0 | b |
| Maize—yellow | 245 | 2.8 | 270 | 0.29 | 0.11 | 2.1 | 0 | b |
| Rice—unhulled, rough | 236 | 1.4 | — | 0.33 | 0.06 | 5.6 | — | b |

and Chew (1976) found the total essential amino acid content for cassava leaf protein to be similar to that found in hen egg and greater than that in oat and rice grain, soybean seed and spinach leaf.

The digestibility of cassava leaf protein has been investigated by Luyken et al. (1961) who found the digestibility to be 80% for the protein in young leaves and 67% for the protein of older leaves. However, they found the percent net protein utilisation to be low, 32 in young leaves and 39 in old leaves, although this could be increased to 61 by the addition of the limiting amino acid, methionine. Condensed tannins, found in cassava leaf blades, may be partially responsible for the low protein utilisation, due to the formation of indigestible tannin-protein complexes or tannin effects on enzyme activity (Reed et al., 1982). The average digestibility of cassava LPC was found to be 56.6% (Fafunso and Oke, 1976).

Feeding trials have been carried out to determine the value of cassava leaves and cassava LPC as supplements to the diet (Adrian and Peyrot, 1971; Nandakumaran et al., 1978). As the leaves and LPC are deficient in methionine they are not suitable for use alone as protein supplements for diets based on the cassava roots that are also methionine deficient, unless the relatively cheap synthetic methionine is also added. However, they can be a valuable addition to lysine-deficient diets such as those based on rice, wheat, sorghum or millet. Using cassava leaves to provide 2 g protein per 100 g diet based on sorghum, the growth rate of rats was doubled and the digestibility of the diet not decreased. Adding extra lysine further improved the protein efficiency ratio of the diet (Adrian and Peyrot, 1971).

Earlier work demonstrated the effect of preparation method on the nutritive value of cassava leaves (Pechnik and Guimaraes, 1962, 1963; Pechnik et al., 1962). A diet of cassava-root flour supplemented with cassava leaves previously dried at 70–80°C, produced no growth response in rats, whereas a diet containing leaves dried at room temperature (about 25°C) or under refrigeration (about 5°C) promoted a slow growth rate. In both cases the addition of lysine and methionine to the diet produced significant improvements in protein efficiency. When the leaves added to the diet were dried, cooked for 3 h and dried again, even the addition

TABLE 3. PROTEIN CONTENT OF CASSAVA LEAF AS PERCENTAGE OF DRY WEIGHT AND WET WEIGHT.

| Protein content | | |
|---|---|---|
| % Dry weight | % Wet weight | Reference |
| 20.8–25.9 | 7.1–8.9 | Barrios and Bressani, 1967 |
| 32.5–37.40 | | Eggum, 1970 |
| 15.09–21.88 | | Figueiredo and Rego, 1973 |
| 31.6 | | Hall et al., 1975 |
| 25.5 | | Martin et al., 1977 |
| 14.4–33.0 | | Nobre et al., 1973 |
| 15.6–39.8 | 8.8–11.4 | Normanha, 1966 |
| 14.69 | | Oyenuga, 1968 |
| 19.79–31.54 | 6.29–8.30 | Ramos-Ledon and Popenoe, 1970 |
| 26.7–39.9 | 8.79–11.8 | Tupynamba and Vieira, 1979 |
| 29.3–39.4 | 7.35–9.26 | Yeoh and Chew, 1976 |

of lysine, methionine and threonine did not stimulate growth, presumably because of denaturation of the leaf amino acids by heat.

A typical Sierra Leone dish is made from cassava leaves and other foods including fish, groundnuts, capsicums and onions. It was estimated that such a sauce, if consumed in quantities of 150 g per day by an adult, or 75 g by a child, would alone provide the total daily protein requirement and hence such food should be encouraged, especially for children (Pratt, 1978). This estimate was based on the assumption that the digestibility of the protein was about 60% and the true protein about 80% of the crude protein content.

Cassava leaves are rich in vitamin C (Caldwell, 1972; Floch, 1957; Raymond et al., 1941; Watson, 1976) and vitamin A (Abbes, 1956; FAO, 1972) and also contain appreciable quantities of riboflavin (Caldwell and Enoch, 1972). Values of 231 and 482 mg of vitamin C per 100 g fresh leaf have been found in light and dark-coloured leaves, respectively, of cassava cultivars grown in Malaysia (Caldwell, 1972) while values as high as 742 mg per 100 g have been reported in Ghanaian cultivars (Watson, 1976). Average values of riboflavin reported in light and dark-coloured leaves are 0.33 and 0.51 mg per 100 g fresh leaf, respectively (Caldwell and Enoch, 1972), while the vitamin A content has been reported at 11,775 $\mu$g (FAO, 1968) and 8,280 $\mu$g (FAO, 1972) $\beta$-carotene equivalent per 100 g of edible portion.

However, while the vitamin content of the leaves is high, the processing techniques used to prepare the leaves for consumption can lead to large reductions. Boiling, especially the prolonged boiling involved in making typical African soups or stews, for example, results in considerable losses of vitamin C (Caldwell and Gim-Sai, 1973; Fafunso and Bassir, 1976a, 1977; Raymond et al., 1941; Watson, 1976) as is normal with green leafy vegetables. For example, vitamin C content was reduced from 742 to 305 mg per 100 g of leaf by boiling for 10 min (Watson, 1976).

Storage of cassava leaves can also lead to loss of vitamin C (Caldwell and Gim-Sai, 1973). Leaves left uncovered but out of direct sunlight for 24 h, periodically sprinkled with water as is often done in the Malaysian markets, retained only

TABLE 4. AMINO ACID COMPOSITION OF CASSAVA LEAF PROTEIN AND CASSAVA LEAF PROTEIN CONCENTRATE (LPC) AND FAO ESSENTIAL AMINO ACID REFERENCE PATTERN (G/100 G PROTEIN).

| Amino acid | FAO essential amino acid reference pattern | Cassava leaves | | | Cassava LPC |
|---|---|---|---|---|---|
| | | a | b | c | d |
| Alanine | | 5.71 | 5.98 | 6.19 | 6.72 |
| Arginine | | 5.55 | 5.28 | 6.12 | 6.53 |
| Aspartic acid | | 9.57 | 10.14 | 9.63 | 10.8 |
| Cysteine | | 1.29 | 1.37 | 1.04 | 0.49 |
| Glutamic acid | | 10.97 | 10.22 | 10.12 | 13.1 |
| Glycine | | 5.20 | 5.39 | 5.32 | 5.96 |
| Histidine | | 2.27 | 2.23 | 2.56 | 2.26 |
| Isoleucine | 4.2 | 5.10 | 5.01 | 4.84 | 3.93 |
| Leucine | 4.8 | 9.17 | 8.89 | 8.85 | 10.1 |
| Lysine | 4.2 | 6.28 | 7.20 | 6.33 | 5.31 |
| Methionine | 2.2 | 2.07 | 1.65 | 1.71 | 0.57 |
| Phenylalanine | 2.8 | 5.89 | 5.82 | 5.53 | 6.14 |
| Proline | | — | 4.64 | 5.40 | 5.75 |
| Serine | | 4.47 | 5.16 | 4.60 | 6.43 |
| Threonine | 2.8 | 4.53 | 4.92 | 4.73 | 5.41 |
| Tryptophan | 1.4 | 1.77 | 1.47 | 2.07 | — |
| Tryosine | | 4.30 | 4.18 | 3.93 | 4.63 |
| Valine | 4.2 | 5.80 | 5.73 | 5.58 | 5.41 |

Source: a, Eggum, 1970; b, c, Rogers and Milner, 1963; d, Tupynamba and Vieira, 1979.

15% of the original vitamin C content (74 mg per 100 g compared to 494 mg per 100 g fresh leaf). In an earlier study, it was also found that vitamin C was lost rapidly at tropical ambient temperatures. Leaves stored for 1, 2 or 3 days contained 75.1, 45.1 and 37.5 mg vitamin C per 100 g fresh leaf, respectively, compared to 247.6 mg in leaves fresh from the market and 353.2 mg in leaves straight from the plantation (Raymond et al., 1941). An investigation of the effects of cooking leaves on their vitamin $B_1$ content showed that steaming resulted in only a slight loss whereas boiling reduced the original content by half (Van Veen, 1938).

In a typical cassava leaf sauce made in Sierra Leone, despite addition of other vitamin C-containing foods to the sauce, the vitamin C content of the cooked product was less than that of the equivalent amount of fresh leaf, suggesting that the prolonged cooking (2½ h boiling) destroyed much of the vitamin. However, a diet of 75 g of sauce per day for a child under 5 still contributed 28% of the daily requirement of the vitamin (Pratt, 1978). Furthermore, avitaminosis C is relatively uncommon in cassava-growing areas of the tropics, partly because of vitamin C derived from cassava root, and also the ready availability and consumption of fruits and other green vegetables.

## TRADITIONAL CONSUMPTION PATTERNS AND PROCESSING TECHNIQUES

Consumption of cassava leaves is not as widespread as that of the roots, and in many areas where the plant is grown the leaves are not used at all or only when other preferred leaves are unavailable (Jones, 1959). In parts of Zambia,

for example, where cassava is the main staple, the leaves are still somewhat despised and regarded as a poor man's food (Whitby, 1972) and similar attitudes exist in other African countries such as Nigeria and Sudan (Anazonwu-Bello, 1978; Jones, 1959). Under the stress conditions during the Nigerian Civil War, cassava leaves were extensively used in the beleaguered eastern states, although they are seldom eaten there in normal times (Anonymous, 1969). However, in other African countries, such as Zaire, Sierra Leone, Tanzania and Gabon, cassava leaves do form a significant part of the diet (Anazonwu-Bello, 1978; Lutaladio and Ezumah, 1981). A daily intake of cassava leaves as high as 500 g per head was recorded by de Smet (1951) in Zaire, although other authors report figures varying from 40–215 g per day per head, also in Zaire (Adriaens, 1951; Jones, 1959) and 27–98 g in Cameroun (Masseyeff and Cambon, 1955). In Cameroun, consumption varies considerably depending on the season, the highest quantity being eaten during the wet season, when young leaves are appearing more profusely.

In South America, Schwerin (1971) could trace reports in the literature of only 7 aboriginal groups scattered north of the Amazon who consumed cassava leaves. However, he felt that the leaves were probably used more widely than this suggests but their use was overlooked by observers because of their secondary importance in the diet. Cassava leaves are also consumed in parts of southeast Asia such as Java and Sumatra (Terra, 1964) and in the islands of the South Pacific (Massal and Barrau, 1955) but indications of the quantities eaten are not available.

The most common way of preparing cassava leaves for consumption is by pounding or chopping, followed by boiling for several hours. The resulting product may be a thick paste or sauce, or a thinner soup or stew. This basic method is used in all parts of the world where cassava leaves form a regular part of the diet. The chief differences in the final products lie in the nature and proportions of the other ingredients used, which vary according to local tastes and availability.

The additional ingredients may be boiled with the leaves or added at the time of serving. In the Amazon region of South America a dish called *manicoba,* consumed at festivals and commemorations, is prepared by the Amerindians from sweet cassava leaves which are crushed or ground, pounded and then cooked in water for 2 or more days with meats, lard and spices (Anonymous, 1973; Moran, 1976; Normanha, 1966). In African countries groundnuts are frequently cooked with the cassava leaves, other ingredients including, for example, beans, sweet pepper, dried coconuts, bananas, meat or fish, and condiments (Alberto, 1958; Autret, 1957; Mosha, 1972; Whitby, 1972). In Indonesia, the leaves are usually mixed with ingredients such as shallots, chillies, coconut milk and tamarind before pounding and cooking in water (Ochse, 1932).

In areas such as northern Angola (Leitão, 1971) and Uganda (Tallantire and Goode, 1975) the cassava leaves are sun-dried before pounding and cooking. In Zaire, a puree called *saka-saka* is prepared from leaves that are first dried over a fire on a metal plate (Adriaens, 1951). Dried cassava leaves are also stored for later use, sometimes ground into a flour (Velcich, 1963).

It is known that leaves of other *Manihot* species are also eaten. This is particularly true of *M. glaziovii* Muell-Arg., often referred to as *manicoba* or *ceara,* which was introduced to many parts of the world from northeast Brazil as a potential source of rubber, but no definite reports were found in the literature.

## CASSAVA LEAF TOXICITY

The toxicity of cassava and its products is generally associated with the cyanogenic glycoside linamarin, together with small amounts of its methyl derivative lotaustralin (Cooke and Coursey, 1981; Nartey, 1978). Hydrolysis and subsequent release of free hydrogen cyanide from these glycosides is brought about by the action of the endogenous enzyme linamarase in damaged tissue or by heating in the presence of acid. Whilst reports of acute cassava toxicity are rare, chronic toxicity is well recognised. Diets in which cassava roots and their products comprise large proportions of the total calorie intake have been associated with a number of chronic conditions such as ataxic neuropathy, goitre, cretinism (Ermans et al., 1980; Nestel and MacIntyre, 1973) and possibly diabetes (Davidson, 1979).

Linamarin, lotaustralin and linamarase are found in all parts of the plant, with the possible exception of the seeds, and the leaf has been postulated as the site of glycoside synthesis (de Bruijn, 1971, 1973; Cooke and de la Cruz, 1982; Nartey, 1968). It is also interesting to note that the enzyme rhodanese that catalyses the formation of thiocyanate from free cyanide and a sulphate donor has been isolated from cassava leaf tissue (Boey et al., 1976; Chew and Boey, 1972). Rhodanese is present in animal tissue and is thought to be involved in the process of cyanide detoxification, but its possible role and significance in cassava leaves are not known.

Although cassava leaves seldom form major components of human diets, they frequently have higher levels of cyanogens than food products made from the root, especially when extensive processing has taken place; this factor together with the possibility of their increased utilization as a novel source of proteins and vitamins indicates the need for awareness of their potential toxicity. An early study in which cassava leaves were fed to rats showed some degree of toxicity although this depended on conditions under which the leaves were produced (Clark, 1936). More recently Rogers and Milner (1963) attempted to assess the toxicity of lyophilised cassava leaf material in rat diets but were unable to draw a conclusion as the diets were rejected by the test animals. In contrast, pigs fed cassava leaves ad libitum in addition to their basal diet showed no symptoms of cyanide poisoning (Mahendranathan, 1971), although this result may reflect the generally low response of pigs to cyanide in the diet (Hill, 1973). Obviously, the potential toxicity of cassava leaves in such trials will depend on initial levels of cyanogens in the tissues and the extent of detoxification during processing; both factors are discussed below.

Reported levels of cassava leaf cyanide range from approximately 10–110 mg HCN per 100 g fresh leaf weight (Table 5), with higher levels occasionally reported, e.g., 186 mg HCN per 100 g fresh leaf weight (Gondwe, 1974). These levels compare with a normal range of 1.5–40 mg HCN per 100 g in fresh cassava roots (Coursey, 1973), although again the extreme range is considerably greater.

Leaf cyanide levels have frequently been used for screening tests to identify low-cyanide cassava clones in breeding programmes (Esquivel and Maravalhas, 1973; Moh and Allan, 1972; Sadik et al., 1974). However, direct comparisons of leaf and root cyanide levels have often yielded conflicting results. Yeoh and Oh

TABLE 5. LEVELS OF CYANIDE IN FRESH CASSAVA LEAVES.

| Number of cultivars | Age and condition of leaves | Cyanide content mg HCN/100 g fresh weight | Reference |
|---|---|---|---|
| 2 | Full-grown, whole. | 16.2–41.0 | Collens, 1915 |
| n.s.[a] | Leaf stalks removed. | 18.6–24.5 | Raymond et al., 1941 |
| n.s. | Mixed ages. | 40–100 | Charavanapavan, 1944 |
| 7 | Leaves as used for cooking. | 43.4–87.8 | Joachim and Panditteseker, 1944 |
| n.s. | Young leaves. | 59.1–84.7 | |
| n.s. | Old leaves. | 19.1–44.0 | |
| 1 | n.s. | 8.3–16.2 | Wood, 1965 |
| 3 | Young leaves. | 32.0–78.0 | Sinha and Nair, 1967 |
| 18 | Young leaves, petioles removed. | 17.4–62.2 | Chew, 1972 |
| 10 | Young leaves. | 56.8–101.6 | Gondwe, 1974 |
| 4 | Mature leaves. | 40.0–53.0 | |
| 5 | Young leaves. | 85.8–146.4 | Kass et al., 1979 |
| 5 | Old leaves. | 83.5–124.9 | |
| 31 | Young, petioles removed. | 12.5–85.4 | Yeoh and Oh, 1979 |

[a] n.s. Not specified.

(1979) found that leaf cyanide levels were similar to those in root peel but 6 times higher than those in root pulp. This finding was supported by Gondwe (1974), but was contradicted by Muñoz and Casas (1972), who found generally higher levels of cyanide in the roots than in the leaves and could find no overall correlation between the two. In a recent study of 108 cassava clones, only a very low correlation was observed between leaf score for cyanide and the cyanide content of peeled roots (Cooke et al., 1978).

The variation observed in cyanide levels is due to genetic, physiological and environmental differences and has been exaggerated by problems associated with techniques for cyanide assay (Cooke and Coursey, 1981). In general, assay methods depend on the hydrolysis of cassava cyanogenic glycosides to free cyanide which is then isolated and determined. Where autolysis is used to effect the first step, this may be incomplete due to low levels of tissue linamarase and/or unsuitable reaction conditions. This may be a less serious problem in leaves, however, where linamarase levels are generally higher; for example, young expanding leaves have been reported to contain 100 times the activity of peeled roots (de Bruijn, 1971). Acid hydrolysis may also be incomplete and competing side reactions may interfere in both methods. An improved enzymatic assay method has recently been developed to overcome these problems (Cooke, 1978).

Studies in which leaf age and cultivation conditions have been standardised have indicated that there is also a considerable genetic component in the variation of leaf cyanide levels. Chew (1972) obtained a range of 17.4–62.2 mg HCN per 100 g fresh weight in 18 cultivars and similarly Yeoh and Oh (1979) report values of 12.5–85.4 mg HCN per 100 g fresh weight in leaves of 31 cultivars studied.

Leaf maturity (Table 5) is probably one of the most significant factors governing cyanide contents and the decrease in cyanide levels of leaves as they age is well documented (Cooke and de la Cruz, 1982; Gondwe, 1974; Joachim and Panditteseker, 1944; Kass et al., 1979; Sinha and Nair, 1967; Williams, 1979). In ex-

TABLE 6. RELATION BETWEEN AGE AND CYANIDE CONCENTRATION IN LEAF BLADES AND PETIOLES OF 4 CULTIVARS.[a]

| Leaf age | Mg HCN/100 g[b] f.w.b. | | Mg HCN/100 g[b] d.w.b. | |
|---|---|---|---|---|
| | Leaf blades | Petioles | Leaf blades | Petioles |
| Very young, expanding | 19.0–57.0 | 42.0–77.0 | 120.0–330.0 | 450.0–680.0 |
| Just full-grown | 44.0–98.0 | 23.0–71.0 | 200.0–400.0 | 200.0–550.0 |
| Older | 24.0–76.0 | 6.5–43.0 | 90.0–290.0 | 45.0–290.0 |

[a] de Bruijn, 1971.
[b] Values given are the range for the 4 cultivars.
f.w.b. Fresh weight basis.
d.w.b. Dry weight basis.

panding leaves the cyanide concentration in leaf petioles is higher than in the blades whereas in older leaves the reverse is true (Table 6). Although both total cyanide and glycosidic or bound cyanide decrease in level with age, free cyanide tends to increase as the leaf matures and to decrease with the onset of senescence (R. A. Plumbley, pers. comm.).

Leaf cyanide levels are also influenced by the nutritional status of the plant. De Bruijn (1971) found that application of inorganic nitrogen increased cyanide content in the leaves whereas application of potassium or farmyard manure decreased it. He also suggested that the levels of valine and isoleucine, which may be precursors of linamarin, may be raised by treatment with potassium or farmyard manure. The form in which nitrogen is supplied also influences leaf cyanide levels (Sinha and Nair, 1967): urea as a sole nitrogen source tended to result in lower cyanide levels than similar amounts of nitrogen applied as glycine, or as nitrate, nitrite or ammonium ions. Shoots supplied with solutions of 5 amino acids, including valine and isoleucine, produced higher leaf cyanide levels than controls supplied only with distilled water.

Plants exposed to long periods of drought respond with an increased leaf cyanide concentration: this effect can also be produced more rapidly with water-stressed pot plants (de Bruijn, 1971, 1973). This is supported by an early report of Clark (1936) who found that cassava leaves from plants grown under dry conditions were more toxic when fed to rats than leaves from plants plentifully supplied with water.

Shading young plants increased their leaf cyanide levels and a slight diurnal effect has been observed on a dry weight basis which is probably due to fluctuation in total leaf solids (de Bruijn, 1971).

Detoxification of cassava leaves may be partially accomplished by heating or boiling to inactivate linamarase and to drive off free hydrogen cyanide (boiling point 26°C); however, this procedure would be insufficient to remove bound cyanide in the form of linamarin. Recent studies have shown that linamarin administered to rats gives rise to toxicity symptoms similar to those obtained with potassium cyanide (Barrett et al., 1978; Philbrick et al., 1977), suggesting that total detoxification may only be achieved by complete autolysis of linamarin followed by removal of free cyanide.

Although it has been stated that simple boiling or cooking is sufficient to remove cyanide completely (Johnson and Raymond, 1968; Raymond et al., 1941), detailed investigation has shown that small residual amounts of cyanide always persist. Joachim and Panditteseker (1944) found 7 mg HCN per 100 g in leaves boiled for 15 min and since they do not state whether these values were obtained after autolysis or acid hydrolysis, the actual levels may well have been higher. Boiling for 1 h resulted in leaves containing 5 mg per 100 g of acid hydrolysable cyanide (Gondwe, 1974), while minced leaves which had not been heated were shown to be toxic to rats (Clark, 1936) and Charavanapavan (1944) reported that up to 75% of the total cyanide is released as free cyanide on pounding. He recommended chopping of the leaves and boiling in 2 changes of water for 15 min, giving a product containing approximately 5 mg HCN per 100 g. Chopping and crushing the leaves prior to boiling has been recommended since the cyanide content is thus simply reduced to a safer level with the advantage of lessening the cooking time compared with the boiling of whole leaves (de Bruijn, 1971; Williams, 1979).

The probable daily intake of cyanide from a traditional sauce prepared in Sierra Leone was found to be considerably less than the $LD_{50}$ for cyanide in man (Pratt, 1978). It should be noted, however, that whilst the level of cyanide in the cooked sauce after boiling for 2½ h was low (4.8 mg HCN per 100 g), the cyanide content of the uncooked leaves used in its preparation (9.8 mg HCN per 100 g) was also somewhat lower than is common for fresh cassava leaves. Nevertheless, the same author reports that there are no documented cases of cyanide poisoning in Sierra Leone due to consumption of cassava leaves. The danger of chronic cyanide poisoning that has been associated with extensive, prolonged consumption of cassava roots (Nestel and MacIntyre, 1973) remains a possibility.

The drying of cassava leaves for human consumption was investigated by Vitti et al. (1971–1972), who found that drying for 1½ h at 65°C reduced the cyanide content of fresh leaves of 6 cultivars from 70–124 mg per 100 g to 21–44 mg per 100 g. Pechnik and Guimaraes (1961) also measured the cyanide contents of flours prepared from cassava leaves and although their fresh leaves contained less cyanide than those used in the previous study (18 mg per 100 g fresh weight), drying at 70–80°C for 24 h gave a similar level of cyanide in the final product of 23 mg HCN per 100 g. The cyanide level could be reduced to 0.9–4.5 mg per 100 g by predrying leaves for 1–3 h, followed by cooking, pressing and drying at 70–80°C to give the finished flour. A comparison of drying methods was made by Kass et al. (1979). The time taken to reduce the cyanide content of leaves from 100 to 20 mg per 100 g was greatest with shade drying (108 h) followed by sun drying (72 h), whilst hot air drying at 60°C (48 h) was the most efficient method.

A nontraditional use of cassava leaves in recent years has been in the preparation of leaf protein isolates, and the distribution of cyanide in the various processing fractions has been studied (Balasundaram et al., 1976; Fafunso and Bassir, 1976b). A large proportion of the cyanide in the fresh leaves, up to 75%, is lost in the juice following pulping and pressing. The remaining cyanide in the wet-leaf protein fraction is further reduced by drying, particularly when freeze drying or oven drying are used rather than sun or air drying (Fafunso and Bassir, 1976b). Acid hydrolysis of the final product indicates that a low level of bound cyanide (approximately 4.7 mg per 100 g) remains in the finished protein preparation.

A number of other potentially toxic constituents have been reported in cassava leaves. An extremely wide range of oxalic acid levels have been reported: 99–3,000 mg per 100 g fresh leaf weight (Pages, 1955; Pilac et al., 1971; Pratt, 1978; Raymond et al., 1941). In a study of the oxalic acid content of Philippine foods and its relation to available calcium, Pilac et al. (1971) showed cassava leaves to contain 57.2% available calcium and a calcium to oxalate ratio of 1.04. The authors suggest that additional calcium-rich foods would therefore be required in a diet containing cassava leaves. Analysis of a traditional sauce based on cassava leaves in Sierra Leone showed high levels of phytic and oxalic acids. Whereas the content of oxalic acid in the cooked sauce was considerably lower than that of the fresh leaves, the percentage of phytic acid in the edible portions was increased on cooking (Pratt, 1978).

The release of hydrogen sulphide gas from cassava leaves on heating and, to a lesser extent on treatment with ethanol, aniline or water, has been reported and suggested as a potential hazard in the consumption of cassava leaves (Ugochukwu and Osisiogu, 1977). The source of sulphur is obscure, especially as cassava leaves, as already mentioned, are low in sulphur-containing amino acids.

Finally, Clark (1936) noted the presence of a small amount of toxic protein (toxalbumin) in cassava but did not specify the part of the plant from which it was isolated. The potential toxicity of the sulphur and toxalbumin content of the leaves merits further investigation, if the use of cassava leaves is to be encouraged.

## CONCLUSIONS

Cassava leaves offer a good source of supplementary protein and also vitamins A and C and minerals. There are a number of ways of preparing dishes from cassava leaves adding variety to the diet as well as nutrients, and incorporation of other vegetables and meat into these dishes adds further to their nutritive value and organoleptic interest.

The cyanide content of cassava leaves is reduced to very low levels by the traditional processing techniques such as pounding and boiling, albeit with an accompanying loss in nutritional value. However, the problem of chronic toxicity from consumption of cyanide-containing foods should not be ignored, and acute toxicity problems, although virtually unknown, are occasionally reported (Hanlon, 1981). There would appear to be scope for more research into the toxic effects of residual levels of cyanide in prepared cassava leaves. Further investigations are also needed to determine the processing techniques that are most effective in reducing cyanide levels in cassava leaves but at the same time do not lead to too great a reduction in the nutrient content.

Cassava leaves already form a significant part of the diet in some countries but, in contrast, there are many other countries where they are not generally consumed, even though cassava is widely grown and they are, therefore, readily available. Hence, an important protein source is often not being exploited in areas where nutrient, especially protein, deficiency is a common problem, as it can be in those regions where root crops such as cassava are the main staple. It is, therefore, important to stress the potential of cassava leaves and to encourage their use by reeducating people to consider them as a valuable addition to the

diet rather than regarding them as a food associated with poverty. It is hoped that this paper, by summarising the available information, can form a useful first step in this direction.

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# Book Review

**Pearl Millet.** Kenneth O. Rachie and J. V. Majmudar. 307 pp. illus. The Pennsylvania State University Press, University Park, 1980. $29.75.

Pearl millet (*Pennisetum typhoides*) is a tall, robust, quick-growing, annual cereal grass. Used both for grain and fodder, it falls into the same category as maize and sorghum. However, having a higher tolerance for high temperatures and drought, it is especially well suited to semi-arid regions of tropical Asia, Africa and the Middle East, where it provides a staple food for millions. Also, millet grains are both less expensive and more nutritious than others such as rice and wheat. In the southeastern United States, the plant is grown principally for forage.

The authors, participants in the development of new pearl millet hybrids that in the 1960s greatly increased yields in India, have assembled and organized existing knowledge (nearly 1,200 references are cited) on this important economic plant. Organization is by chapters: (1) "Origin and History"—short introduction to its origin and potential; (2) "The Plant"—morphology, genetics, and cytogenetics; (3) "Breeding"—methods, behavior; (4) "Growing the Crop"—cultivation practices in various regions; (5) "The Product"—storage, processing, and utilization of grain and fodder; and (6) "The ICRISAT Millet Improvement Program"—contributed by the International Crops Research Institute for the Semi-Arid Tropics staff headed by D. J. Andrews and reviewing the latest work on pearl millet at the Institute.

Considering the great demand for food in semi-arid tropics and the exceptional potential of pearl millet as a cereal crop, this volume is highly significant. It should be of inestimable value to all workers in this field. The ICRISAT and the Rockefeller Foundation, both of which helped to finance this publication, are to be commended, as well as the authors.

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